Assessment of genotype x environment interaction and stability of sesame (*Sesamum indicum* L.) seed yield under rainfed and supplementary irrigation in central Sudan

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ABSTRACT

Sesame knowledge of genotype x environment interaction (GEI) is advantageous in order to have a cultivar that gives consistently high yield in a broad range of environments and to increase the efficiency of breeding programs and selection of the best genotypes. Fifteen genotypes of sesame (*Sesamum indicum* L.) were evaluated during 2011 and 2012 rainy seasons, at Wad Medani, Rahad (under supplementary irrigation) and Gedarif (under rainfed), to assess genotype x environment interaction and stability of seed yield. A randomized complete block design with four replicates was used in each location. The analysis of variance procedure revealed highly significant differences among the 15 sesame genotypes for seed yield over the eight environments. The mean squares of environment, genotype and genotype x environment interaction were highly significant for seed yield. Both statistical stability models, i. e. Eberhart and Russell (1966) as well as the Additive Main Effect and Multiplicative Interaction (AMMI) analysis, indicated that genotypes Elgezouli, Promo, Um Shagra and Kenana-2 were the most high yielding and stable genotypes and can be recommended for both rainfed and irrigated areas of central Sudan.

INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the most important oilseed crops in Sudan, both for local consumption and for export (Ahmed, 2008). It is widely grown under rainfed areas and more recently its commercial production was initiated at irrigated sites like River Nile State and Gezira Agricultural Scheme.

In Sudan, the ultimate objective of the sesame breeding program, since its inception in the early nineteen fifties has been the development of high yielding, non-shattering varieties for mechanized crop production (Walton, 1959; Tahir, 1964; Mahmoud, 1966). Also, the development of varieties which can be adapted to a wide range of diversified environments, is the ultimate goal of sesame breeders in Sudan. However, in sesame breeding program, many potential genotypes are usually evaluated in different environments (locations and years) before selecting desirable ones for release and commercial cultivation. A desirable cultivar is one that does not only yield well in its area of initial selection, but also maintains the high yielding ability over a wide range of environments within its intended area of production. Therefore, knowledge of genotype x environment interaction (GEI) is advantageous in order to have a cultivar that gives consistently high yield in a broad range of environments and to increase the efficiency of breeding program and selection of the best genotypes.

Genotype by environment interaction (GEI) is a major complication in plant breeding. So, the G x E interaction can be partitioned in studies on the adaptability and phenotypic stability. Adaptability is the capacity of a genotype to make use of environmental conditions to warrant a high yield level; stability, on the other hand, is related to the yield maintenance or yield predictability in the diverse environments. There are various methods of analysis of adaptability and stability designed to evaluate a genotype group tested in a series of environments. Among these, the most widely used are the ones based on linear regression (Eberhart and Russel, 1966), and a more recent application method called AMMI analysis (Additive Main effects and Multiplicative Interaction analysis) that combines a univariate method for the additive effects of genotypes and

environments, with a multivariate method for the multiplicative effect of G x E interaction (Zobel *et al.*, 1988).

The objectives of the current study were to assess G x E interaction in sesame seed yield of 15 genotypes over 8 environments with the help of Eberhart and Russel's regression model (1966), and the AMMI model, and to determine the most stable genotypes.

MATERIALS AND METHODS

Fifteen sesame genotypes, four local varieties (were collected from Gedarif area), six released varieties (were collected from the sesame breeding program of ARC-Sudan) and five advanced breeding lines (were provided by Dr. Khalafalla Ahmed Ali), were analyzed using a randomized complete block design with four replicates. The name and cultivars/varieties code numbers of sesame genotypes are given in Table 1. The experiment was conducted during 2011 and 2012 rainy seasons at four locations. The three irrigated locations (Wad Medani, sites 1 and 11 and Rahad) and one rainfed location (Gedarif) lied within the central clay plains of the Sudan and characterized by heavy, alkaline clay soil, with a pH of around 8.5 and low in nitrogen and organic matter contents. For easy reference, the location/year/season combination was considered as an environment and given a number (Table 2).

The material was sown on the first week and second week of July, 2011 and 2012, respectively, in the four locations. At each environment, the seeds were sown manually in two rows, 5 m long and 0.80 m apart, in holes spaced 0.10 m apart within the row, with a seed rate of 3 kg/ha. The total rainfall at Wad Medani locations (sites 1 and 11) in the first and second seasons were 450 mm and 560 mm, respectively, so eight supplementary irrigations were applied in the first season and five in the second season. At Rahad location, the total rainfall was 454 mm in the first season with four supplementary irrigations and 675 mm with three supplementary irrigations in the second season. The total rainfall at Gedarif were 515 mm (first season) and 600 mm (second season) without supplementary irrigation. The experiments were weeded before thinning and then whenever necessary.

The data were collected on days to 50% flowering, days to maturity, height to first capsule (cm), number of capsules per plant, plant height (cm), capsule length (cm), number of seeds per capsule, 1000-seed weight (g) and seed yield (kg/ha), but in this publication only data on seed yield was presented.

The analysis of variance procedure was used to test differences among genotypes within each season, location and combined. Eberhart and Russell (1966) stability model was performed. In addition, the Additive Main Effect and Multiplicative Interaction (AMMI) analysis was carried out to show the stability and pattern of adaptation of sesame genotypes in eight environments, using IRRISTAT (2005) statistical analysis package for seed yield data analysis.

Table 1. Genotypes used in the study.

Genotype code	Genotype name/pedigree	Status
G1	Gd2003-S-P-S-N-23	Advanced breeding line
G2	Gd2002ob-N-2-39	Advanced breeding line
G3	Gd2002-S-P-S-N-12	Advanced breeding line
G4	Gd2002S-P-S-N-14	Advanced breeding line
G5	Gd2008-SP-S-N-1	Advanced breeding line
G6	Kenana-2	Released variety
G7	Khidir	Released variety
G8	Promo	Released variety
G9	Um Shagra	Released variety
G10	Gedarif-1	Released variety
G11	Abu Sofa	Local variety
G12	Jugam	Local variety
G13	Abu Radoum	Local variety
G14	Elgezouli	Released variety
G15	Abu Sandoog	Local variety

Table 2. Locations and environments.

Location name/ agro-ecological Character	Medani site I Gezira University Experimental Farm	Medani siteII Gezira Research Station Farm	Rahad Rahad Research Station Farm	Gedarif Gedarif Research Station Farm
Latitude	14° 25′ N	14° 25′ N	13° 31′ N	14° 1′ N
Longitude	33° 29′ E	33° 29′ E	34° 32′ E	35° 21′ E
Altitude (m.a.s.l)	407	407	570	592
Environment and	E1 (2011)	E2 (2011)	E3 (2011)	E4 (2011)

Season code	E5 (2012)	E6 (2012)	E7 (2012)	E8 (2012)
Clay content (%)	54	54	60	75
Annual rainfall	450 (2011)	450 (2011)	545 (2011)	515 (2011)
(mm)	560 (2012)	560 (2012)	675 (2012)	600 (2012)

RESULTS AND DISCUSSION

The analysis of variance for seed yield and its components over different environments is presented in Table 3. For easy reference, the location/year/season combination was considered as an environment and given a number (Table 2). The mean squares of environment, genotype and genotype x environment interaction were highly significant ($p > 0.01$) for seed yield and yield components. Highly significant differences were observed among environments indicating that the genotypes under study were under diverse seasons and locations. Significant differences among genotypes for seed yield indicated that genotypes differed in their genetic potential for seed yield and its components. The G x E interaction was also highly significant for seed yield. This shows that genotypes react differently at different environments for seed yield and hence necessitated the use of stability, since the G x E interaction were highly significant.

Table 3. Mean squares from combined analysis of variance of seed yield and its components measured over different environments.

SOV	d.f	DF	DM	PH	NCP	HFC	CL	NSC	SW	SY
Environment(E)	7	2738**	10167**	29109**	10747**	17890**	2.1**	6889*	3.3**	1840368**
Genotype (G)	14	271**	217**	1878*	615**	1159**	5.2**	332**	3.4**	276958**
G x E	98	14**	29**	160**	190**	121**	0.1**	12**	0.2**	40943**
Error	357	4	6	126	120	63	0.1	55	0.1	27118

DF= days to 50% flowering, DM= days to maturity, PH= plant height, NCP= number of capsules per plant, HFC= height to first capsule, CL= capsule length, NSC= number of seeds per capsule, SW= 1000-seed weight and SY= seed yield/ha.

Mean squares for genotype (G), environment (E) and G x E of all traits were significant at 0. 001 probability level.

The significant G x E mean squares is a clue for genotype adaptation to certain environments. Hence, genotypes or varieties that are adapted to a wide range of environmental conditions with high average yields should be selected, by some measures, as superior genotypes. These measures are usually different statistical stability models in their parametric (univariate) or nonparametric (multivariate) approaches. However, Eberhart and Russel (1966) emphasized that both linear and non-linear components of G x E interaction should be particular genotypes. They also suggested considering both the linear regression coefficient (b_i) and deviation from regression (S^2d) for phenotypic stability. The data on the three stability parameters, mean performance, regression coefficient (b_i) and deviation from regression (S^2d) for seed yield are presented in Table 4.

According to Eberhart and Russel (1966) stability model (an example of a parametric and univariate analysis approach), the results in Table 4 showed clear differences in values of regression coefficient (bi) greater than or around unity and relative minimal deviation from regression. This means that these sesame genotypes are more responsive to environmental changes, which give the breeder an advantage to select genotypes for both

adverse and favorable environments. Across all environments, the genotype Promo gave relatively high average seed yield (698 kg/ha) and had bi value of 1.06, which was very close to unity indicating its adaptability to the range of testing environments. Also, it had S^2d value of 0.4468, indicating that this genotype had stable seed yield over a wide range of environments. Consistent high mean seed yield demonstrated by the genotype Promo and its adaptability and stability makes it a suitable genotype for cultivation over a wide range of environments (both irrigated and rainfed). Also, it was emphasized that both linear (bi) and non-linear (S^2d) components of G x E interaction are necessary for judging the stability of a genotype. Therefore, the genotypes Gd2008-S-P-S-N-1 and Abu Sandoog gave lower seed yield (613 and 550 kg/ha, respectively) compared with the genotype Promo, but had a regression coefficient (bi) approximating 1.00 coupled with an S^2d of zero, indicating average stability (Table 4). This means that both genotypes Gd2008-S-P-S-N-1 and Abu Sandoong may be stable under favorable conditions of supplementary irrigation or heavy rainfall. On contrast, the genotypes Um Shagra, Elgezouli and Kenana-2 gave the highest seed yield of 752 kg/ha, 747 kg/ha and 686 kg/ha, respectively, but their regression coefficients (bi) were far away from unity and their deviation from regression (S^2d) was too large (Table 4). The other genotypes like Gd2002-S-P-S-N-12 (447 kg/ha) and Jugam (440 kg/ha) had the lowest average seed yield, and their regression coefficients (bi) were far away below unity with almost the largest deviation from regression (S^2d) in the group (Table 4) and might be useful under the conditions of erratic, unstable and low rainfall environments.

In the current study, Eberhart and Russel (1966) model analysis suggested the genotypes Promo, Elgezouli, Keana-2 and Um Shagra as the highest yielding genotypes over the eight environments under study. Therefore, this parametric approach (univariate) gives only the individual aspect of stability but cannot provide an overall picture of the response. Since, the genotype response to environments is multivariate, so the Additive Main effect and Multiplicative Interaction (AMMI) analysis was used to solve such a problem (Gauch and Zobel, 1988; Nachit *et al.*, 1992).

Table 4. Stability parameters across all environments for seed yield by Eberhart and Russel model.

Genotype	Seed Yield (kg/ha)	bi	S^2d
1- Gd2003-S-P-S-N-23	607	0.92	14279
2- Gd2002-ob-N-2-3-39	599	1.17	2959
3-Gd2002-S-P-S-N12	447	0.56	9446
4-gd2002-S-P-S-N-14	557	0.85	4728
5- gd2008-S-P-S-N-1	613	0.99	3893
6-Kenana-2	686	1.46	7781
7-Khidir	545	0.82	2080
8-Promo	698	1.06	4468
9-UmShagra	752	1.25	11152
10-Gedarif -1	618	1.23	16497
11-Abu Sofa	645	0.86	8925
12-Jugam	440	0.58	18531
13-Aubradoum	643	1.10	10017
14-Elgezouli	747	1.18	17408
15-Abu Sandoog	550	0.97	4358

bi= Slopes of regression of variety means on site index.
S^2d= Deviation from regression component of interaction.

In the present study, partitioning the interaction of G x E was based on the AMMI stability technique (Zobel *et al.*, 1988). Multivariate statistical methods such as AMMI have been introduced to explore multidirectional aspects and an attempt to extract more information from this component. However, results of AMMI analysis of mean seed yield for the four locations showed significant differences (P<0.01) among the genotypes, the environments and G x E interaction (Table 5) and this result also showed that 62% of the total sum of squares was attributable to environmental effects, only 18.7 to genotypic effects and 19.3 to GEI effects (Table 5). Hence, these results of AMMI analysis of variance showed that 62% of the total sum of squares was attributable to environmental effects. A large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing most of the variation in seed yield.

In addition to that, results from AMMI analysis (Table 5) showed that the first principal component axis (IPCA 1) of the interaction captured 33.4% of the interaction sum of squares in 20 degrees of freedom. Similarly, the second principal component axis (IPCA11) explained a further 28.6% of variation due to G x E interaction sum of squares. The mean squares for IPCA 1and PCA 11 were highly significant at P = 0.01 and cumulatively contributed 62% of the total GEI. Therefore, the partitioning of the interaction sum of squares was effective for seed yield. The combined mean squares (MS) for the two IPCA axes were 4.0 times that of the residual MS for seed yield. Thus, the post-predictive evaluation using an F-test at P = 0.01 suggested that two principal component axes of the interaction were significant for the model with 38 degree of freedom. Thus, the interaction of the 15 sesame genotypes with eight environments was best predicted by the first two interaction principal component of genotypes and environments.

Table 5. Additive Main effect and Multiplicative Interaction (AMMI) analysis of variance for seed yield (kg/ha) of 15 sesame genotypes over eight environments.

Source of variation	d.f	S.S	SS %	M.S	F-value
Treatment	119	20772577		174559	9.26***
Genotype	14	3877420	18.7	276959	14.69***
Environment	7	12882706	62.0	1840387	10.92***
Block	24	4043529		168480	8.92***
Interaction	98	4012451	19.3	40943	2.17***
IPCA1	20	1340943	33.4	67047	3.56***
IPCA2	18	1148178	28.6	62788	3.38***
Residual	60	1523329		25389	1.35**
Error	336	6333172		18849	
Total	479	31149277		65030	

d.f= degrees of freedom, S.S= sum of squares, SS%= sum of squares explained, M.S= mean square,
*,**,***, Significant at 0.05, 0.01 and 0.001 probability levels respectively, otherwise non-significant.

Results from Table 6 connected with Fig. 1, indicated that the genotypes and environments showed considerable variation in mean seed yield. Moreover, genotypes or environments with large negative or positive IPCA 1 scores had high interaction, while those with IPCA 1scores near zero (close to the horizontal line) had little interaction across environments and *vice versa* for environments (Crossa, 1991) and are considered more stable than those further away from the line. Consequently, genotypes G 2, G 10, G 5, G 13, G 11, G 4, G 9 and G 14 responded positively to productive environments E 1, E 4, E 3 and E 2. While genotypes; G 6, G 8, G 1, G

15, G 7 G 12 and G 3 responded negatively to productive environments E 7, E 8, E 6 and E 5. Therefore, genotypes; G 2, G 10, G 5, G4, G 14, G 6, G 7 and G 15 were adapted to environments E 2, E 3 and E 8 (both irrigated and rainfed environments) as shown in Table 6 and Fig. 1. Therefore, the analysis of the genotype and environment parameters resulting from AMMI showed that the best yielding and stable genotypes were Elgezouli, Promo and Kenana-2.

Table 6. First four AMMI selections per environment.

Environment	Mean	Score	1	2	3	4
E1	717	12.5	G9	G13	G10	G11
E2	626	1.0	G9	G13	G10	G6
E3	595	6.7	G14	G9	G11	G8
E4	682	10.4	G14	G9	G11	G6
E5	919	-5.7	G14	G8	G6	G9
E6	561	-11.4	G8	G1	G6	G10
E7	360	-9.6	G8	G6	G1	G14
E8	418	-3.9	G14	G8	G6	G9

E1= Medani 1 (Gezira University Experimental Farm 2011), E2= Medani 11 (Agricultural Research Corporation Farm 2011), E3= Rahad 11 (Rahad Research Farm 2011), E4= Gedarif 11 (Gedarif Research Farm 2011), E5= Medani 1 (Gezira University Experimental Farm 2012), E6= Medani 11 (Agricultural Research Corporation Farm 2012), E7= Rahad 12 (Rahad Research Farm 2012), E8= Gedarif 12 (Gedaref Research Farm 2012). G1= Gd2003-S-P-S-N-23, G6= Kenana-2, G8= Promo, G9= Um Shagra, G10= Gedarif-1, G11= Abu Sofa, G13= Abu Radoum and G14= Elgezouli.

CA scores

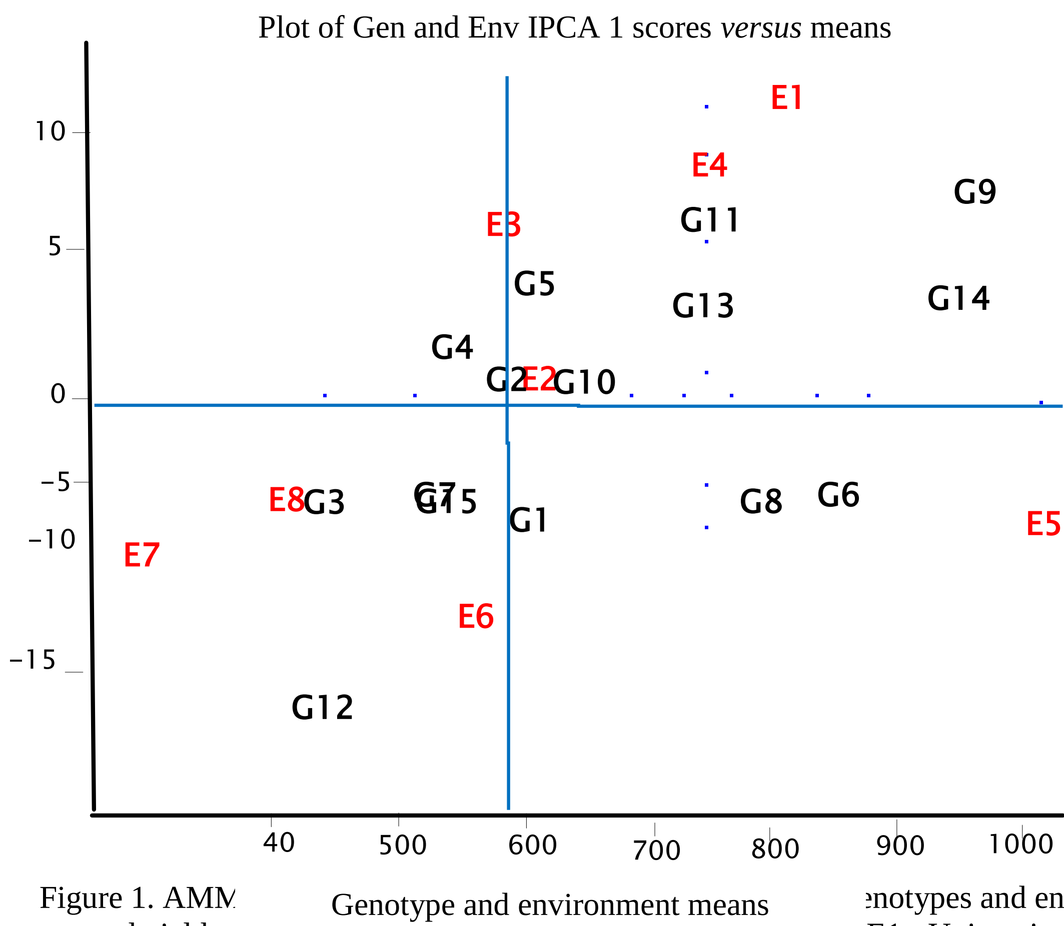

Figure 1. AMM ... enotypes and environments on seed yield of 15 sesame genotypes grown in 8 environments. E1= University of Gezira, 2011, E2= Agricultural Research Corporation, 2011, E3= Rahad Research Station, 2011), E4= Gedarif Research Station, 2011, E5=University of Gezira, 2012, E6=Agricultural Research Corporation, 2012, E7= Rahad Research Station 2012, E8= Gdaref Research Station 2012. G1= Gd2003-S-P-S-N-23, G2= Gd2002-ob-N2-23, G3= Gd2002S-P-S-N-12, G4= Gd2002-S-P-S-N-14, G5= Gd2008-S-P-S-N-1, G6= Kenana-2, G7= Khidir, G8= Promo, G9= Um Shagra, G10= Gedarif-1, G11= Abu Sofa, G12= Jugam, G13= Abu Radoum G14= Elgezouli and G15= Abu Sandoog.

CONCLUSION

In conclusion, both parametric and nonparametric approaches of sesame seed yield stability statistical analysis (Eberhart and Russel as well as AMMI) agreed in identifying the genotypes or varieties Promo, Elgezouli, Kenana-2 and Um Shagra as the higher yielding, stable varieties over most of the environments covered by the current study.

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تقويم التفاعل الوراثي-البيئي وثبات درجة انتاجية بذور السمسم (*Sesamum indicum* L.) بالري المطري والتكميلي في وسط السودان

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الخلاصة

من ميزات دراسة التفاعل الوراثي- البيئي في محصول السمسم معرفة افضل الاصناف ذات الانتاجية العالية في مدي واسع من البيئات المختلفة مما يزيد من كفاءة برامج التربية المستعملة وانتخاب افضل الاصناف. تم تقويم 15 سلالة من السمسم في الموسمين الزراعيين 2011 و2012م في ثلاثة مواقع هي مدني، الرهد (ري تكميلي) والقضارف (ري مطري)، وذلك لتقويم التفاعل الوراثي والبيئي وثبات درجة انتاجية بذور السمسم. استخدم تصميم القطاعات العشوائية الكاملة بأربع مكررات. اظهرت نتائج تحليل التباين لعدد 15 سلالة من السمسم فروقات معنوية عالية جدا لمعظم الصفات التي درست في كل المواقع والمواسم مع معنوية للتفاعل الوراثي والبيئي لإنتاجية البذور. بناءاً علي نماذج التحليل Eberhart and Russel (1966) وAdditive Main Effect and Multiplicative Interaction(AMMI) لتحديد ثبات الاداء معاً وجد ان انتاجية بذور الاصناف الجزولي، برومو، ام شجرة وكنانة-2 ثابتة وعالية في كل المواقع والمواسم. وبناءاً علي ذلك يوصي بزراعة هذه الاصناف في المناطق المطرية والمروية في وسط السودان.